International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)
ISSN(P): 2249–6890; ISSN(E): 2249–8001
Vol. 9, Issue 5, Oct 2019, 689–698

DYNAMIC IMPACT ANALYSIS ON ATV UPRIGHT

U. YASHVANTH[1], MOHAMMAD RAFFI[2], G. RAGHU VAMSI REDDY[3],
Dr. C. PRASAD[4] & Dr. K. N. BALAN[5]

[1,4]*Assistant Professor, Department of Automobile Engineering Hindustan Institute of Science, Chennai, India*
[2,3]*Student, Department of Automobile Engineering Hindustan Institute of Science, Chennai, India*
[5]*Associate Professor, Department of Automobile Engineering Hindustan Institute of Science, Chennai, India*

ABSTRACT

Uprights play a vital role carrying the complete wheel assembly with it and attached to vehicle suspension system. The knuckle has to design in order to sustain all the loads acting on the vehicle during the course of dynamic motion. The loads taken up by tire's are directly transferred to the uprights, because tire with upright forms a single assembly unit, but near the upright hard point the suspension forms a linkage, which even takes sprung mass loads. Therefore the knuckle in commercial vehicle is manufactured using EN graded material or the cast iron, but the same can be designed and manufactured using aluminium material which can offer same strength characteristics but with decreased in overall sprung mass weight.

KEYWORDS: Impact Analysis, ATV Upright, EN Steel, Cast Iron, Design of Upright & Vehicle Dynamics

Received: Apr 19, 2019; **Accepted:** May 14, 2019; **Published:** Sep 21, 2019; **Paper Id.:** IJMPERDOCT201960

Original Article

INTRODUCTION

The uprights also called as knuckle or steering knuckle. The upright acts as an intermediate system that connects the vehicle sprung mass to the dynamic rotational vehicle wheels. It carries free single axis rotating hub coupled with the vehicle wheel, brake caliper assembly and connects the vehicle wheel assembly to the steering and suspension system of the vehicle.

The steering knuckle consist a spindle attached to it carrying the wheel hub. It has four hard points in which two of the hard points used to couple the suspension assembly with the wheel assembly. One used to couple the steering tie rod linkage with the wheel assembly and the last pivot point used to mount the braking system on upright, in order have indirect connection with the brake rotor assembled over the vehicle hub.

The steering knuckle plays a vital role over vehicle dynamics. It has a contribution over the vehicle directional and vehicle straight-line stability characteristics. The turning radius of the vehicle can easily varied by varying the track arm angle of the upright and similarly the caster angle by creating the difference in angle of upper and lower pivot point of the suspension with respect to centre of the tire. The king pin axis can be easily altered by varying the difference in length between the suspension upper and lower pivot arm. If the length of the upper suspension pivot arm increased with decrease in length of the lower suspension pivot arm can increase in king pin inclination. The increase in king pin inclination changes the suspension geometry and can create difference of length in upper and lower suspension wishbone. The difference in length of the suspension wishbone can create short and long arm wishbone (SLA) suspension geometry

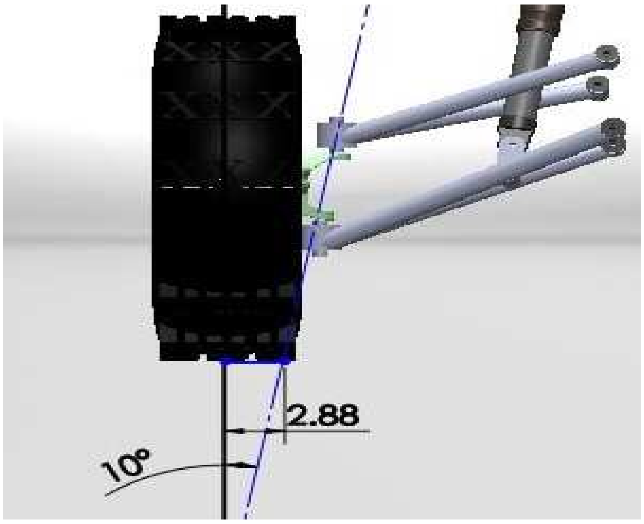

Figure 1: King pin Inclination and Scrub Radius.

MATERIAL SELECTION

The upright experiences four types of major different forces acting on the tire in different axis. The uprights are usually commercially manufactured using cast iron or EN graded steel material. Bending and deformation forces exerted on the upright and hence it needs material with high yield strength and high ultimate tensile strength. The material like cast iron and steel can satisfy the requirements but the density of both the material is higher which can increase the weight of the complete assembly. Similarly, the aluminium in other hand have same amount of ultimate tensile strength and yield strength with similar machining properties but weighing lesser in weight can be used to manufacture the upright. The use of aluminium can reduce the wheel unsprung mass to contribute soft ride handling characteristics and can increase the fuel efficiency of the vehicle. The material properties of Aluminium T6 7075 is given below in the table.

Mechanical and Physical Properties

Table 1: Mechanical and Physical Properties of Aluminium

(Al T6 7075)		
Physical Properties		
Quantity	**Value**	**Unit**
Density	2.81	g/cm^3
Mechanical Properties		
Quantity	**Value**	**Unit**
Tensile strength, Ultimate	510–540	GPa
Tensile Strength, yield	430–480	GPa
Young's Modulus	71.7	GPa
Poisson Ratio	0.33	—

Chemical Properties

Table 2: Chemical Properties of Aluminium

Element	% Weight
Copper, Cu	1.2–2
Manganese, Mn	MAX 0.3
Silicon, Si	0.4 Max
Chromium, Cr	0.18–0.28
Magnesium, Mg	2.1–2.9
Phosphorous, P	0.05 Max

CAD DESIGN

The computer aided design is been made with accordance to the simulated output of suspension analysis. Through suspension analysis, the hard-points for suspension and steering tie-rod mountings is plotted using three-dimensional coordinate geometry in Dassult's Solidworks 2018 Design software. With the fixed hard-points of suspension, steering toe-rod and wheel center, the design made in order to attain the caster angle and kingpin inclination on the upright. The upright designed with more amount of fillets and chamfer to avoid sharp edges, which are prone to crack development. The attributes considered for designing the upright shown below in table.

Table 3: Consideration for CAD Design

Attributes	Units
Material of knuckle	Al T6 7075
Castor	10 degrees
Scrub Radius	14 mm
Kingpin Inclination	10 degrees
Length	110 mm

The pivot-to-pivot distance of suspension ball joint mounting on an upright is maintained short in order to increase the ground clearance for lower suspension A-arm wishbone. The track arm aligned in according to the suspension instantaneous point. Minimum required gap maintained between the track arm for the mounting of steering tie-rod. The brake caliper mounting point made in according to the centre-to-centre pivot mounting distance of the caliper. The CAD model of the upright is shown in below given figure.

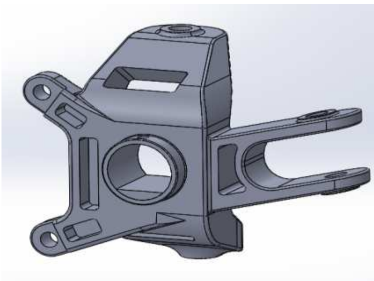

Figure 2: Upright Front Preview.

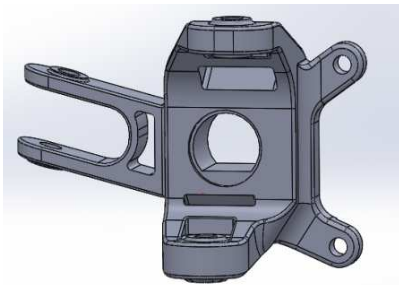

Figure 3: Upright Rear Preview.

FORCES ON STEERING KNUCKLE

The number of forces acting on the upright during the course of dynamic motion is listed below,

- Lateral forces
- Bump forces
- Braking torque
- Push and pull from steering arms

The force of action on the tire during the high speed cornering of the vehicle known as lateral forces calculated in Newton. Similarly, the force acting when the suspension goes on to jounce over an irregular track, the force exerted on tire normal and opposite to the action of centre of gravity known as bump force. When the brakes are applied, the amount of torque generated by the brake caliper exerts a force over the fixed point of the brake caliper with respect to the opposite motion of the tire is called as braking torque over the knuckle pivot point. The steering system is used to provide direction to the vehicle in motion or static, which in return exerts push and pull force on the upright to either push the wheel

assemble away or pull the wheel assembly in order to make an arc of tire up to certain angle for directional turning of the vehicle.

CALCULATION

Note: The calculations done are according to the vehicle specifications that we are using. The values considered and output may differ for different vehicle and its specification.

Steering Effort Calculations

Table 4

Attributes and Annotation	
l	Length of Contact Foot Print
b	Width of Contact Foot Print
δ	Deflection of Tire
D_c	Outer Diameter of Tire
W	Front Axle Weight
k	Tire Stiffness
K	Radius of Gyration
e	Scrub Radius
h	Effective Torque Arm
μ	Coefficient of Friction
θ	King Pin Inclination, Rad
α	Inner Wheel Angle, Rad
L	Knuckle Length
D_p	Pitch Diameter of Pinion
λ	Angle Between IBJ (Inner Ball Joint) and OBJ (Outer Ball Joint) Of Tie Rod, Rad

Push and Pull of Steering Arm

Deflection of tire is,

$$\delta = \frac{W/2}{k}$$

$$\delta = \frac{(80/2)*9.81}{62.643}$$

$$\delta = 6.26\, mm \tag{1}$$

Length of contact footprint,

$$\frac{l}{2} = \sqrt{\delta} * \sqrt{Dc - \delta} * 0.7$$

$$\frac{l}{2} = \sqrt{6.26} * \sqrt{558.8 - 6.26} * 0.7$$

$$l = 41.16\, mm \tag{2}$$

Width of contact footprint,

$$\frac{b}{2} = \sqrt{\delta} * \sqrt{Wt - \delta}$$

$$\frac{b}{2} = \sqrt{6.26} * \sqrt{129.54 - 6.26}$$

$$b = 27.78mm \tag{3}$$

Area of contact footprint,

$$A = l * b$$

$$A = 1143.4248\ mm^2 \tag{4}$$

Polar moment of area,

$$Io = \frac{A * (l^2 + b^2)}{12}$$

$$Io = \frac{1143.4248 * (41.16^2 + 27.78^2)}{12}$$

$$Io = 2349.617 \ * \ 10 \ ^\wedge \ 2\ mm^4 \tag{5}$$

Radius of gyration,

$$K = \sqrt{\frac{Io}{A}}$$

$$K = \sqrt{\frac{2349.617 * 10 \ ^\wedge 2}{1143.4248}}$$

$$K = 14.33\ mm \tag{6}$$

Effective torque arm,

$$h = \sqrt{e^2 + K^2}$$

$$h = \sqrt{25.4^2 + 14.33^2}$$

$$h = 29.163\ mm \tag{7}$$

Torque required to turn wheels about KPI is,

$$Tk = \mu * \frac{W}{2} * h$$

$$Tk = 0.6 * \frac{80*9.81}{2} * 29.163$$

$$Tk = 6866.136\ Nmm \tag{8}$$

Steering Arm Moment is,

$$SAM = \frac{e * \frac{W}{2} * sin\theta * (1 - cos\theta)}{sin\ \alpha}$$

$$SAM = \frac{25.4 * \frac{80 * 9.81}{2} * sin\ 0.157 * (1 - cos\ 0.157)}{sin\ 0.785}$$

$$SAM = 28.63\ Nmm \tag{9}$$

Total torque is,

$$Tt = Tk + SAM$$

$$Tt = 6866.136 + 28.63$$

$$Tt = 6894.766304\ Nmm \tag{10}$$

The force acting on tie rod is,

$$Tf = \frac{Tt}{L}$$

$$Tf = \frac{6894.766}{110}$$

$$Tf = 62.67\ N \tag{11}$$

Brake Torque

$$\boldsymbol{T = r * c * f}$$

r = Radius of Rotor

c = Coefficient Of Friction between Rotor and Brake Pad

f = Piston Force on Rotor

T = 1486.98 * 0.2

T = 297.39 Nm (12)

Lateral Force

$$\boldsymbol{F = \frac{sprung\ mass\ at\ front * v^2}{R}}$$

$$= \frac{\mathbf{65 * 10.5^2}}{\mathbf{2.5}}$$

= 2866.5 N (13)

R = Turning radius

V = Vehicle velocity

Bump Force

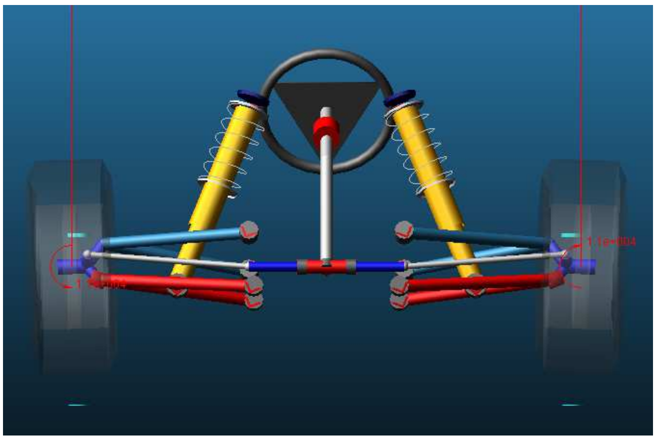

Figure 4: Suspension Parallel Wheel Travel.

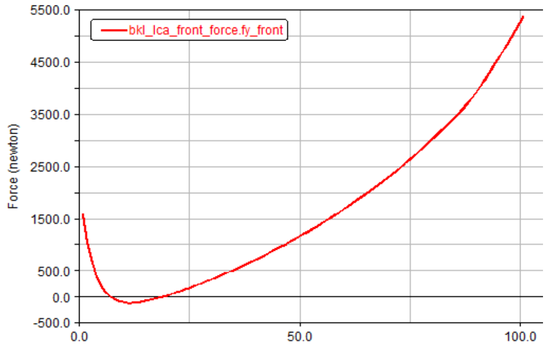

Figure 5: Bump Force Graph on Uprights.

The Parallel Wheel Travel Suspension Simulation figure 4 carried out in order to find the bump force acting over the vehicle dynamically. The weights of all the subsystems and the uprights were provided. The weight of the upright was calculated in Solidworks 2018 software. The system simulated over a bump of six inches, with vehicle tire diameter of twenty-two inches and sprung mass of hundred kilograms. The force acting on all the components of the body was predicted in which the fore acting on the steering knuckle plotted in graph as shown in the figure 5.

From the above graph, the bump force exerted on the upright is 5540 N. (14)

ANALYSIS

An effective analysis of steering knuckle is required to ensure that upright can withstand all sorts' road conditions of it takes. The Finite Element Analysis carried out using Ansys Workbench 18.0. A static structural analysis carried out by a remote displacement support in one axis of wheel travel and forces applied on all the hard points. The attributes considered for analysis are listed in the below table.

Table 5: Analysis Setup

Analysis Type	Static Structural
Meshing Method	Beam Method
Element Type	Hex Dominant
Element Size & Type	2.45 mm & 3D
Number of Elements	6,79,800
Solver	Sparse Direct

Mesh Preview

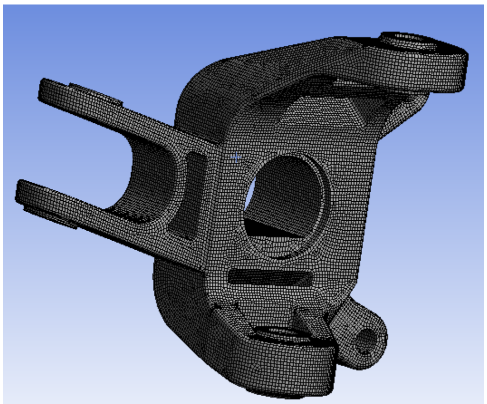

Figure 6: Mesh Preview.

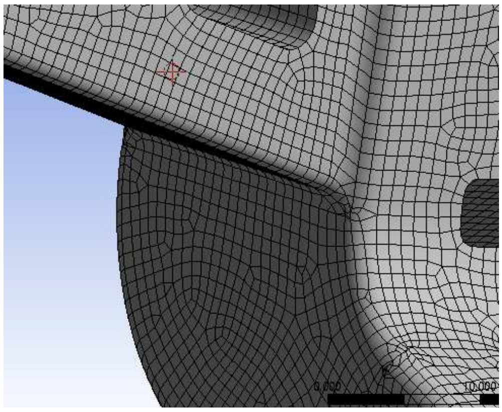

Figure 7: Magnified Mesh view.

Analysis Model Setup

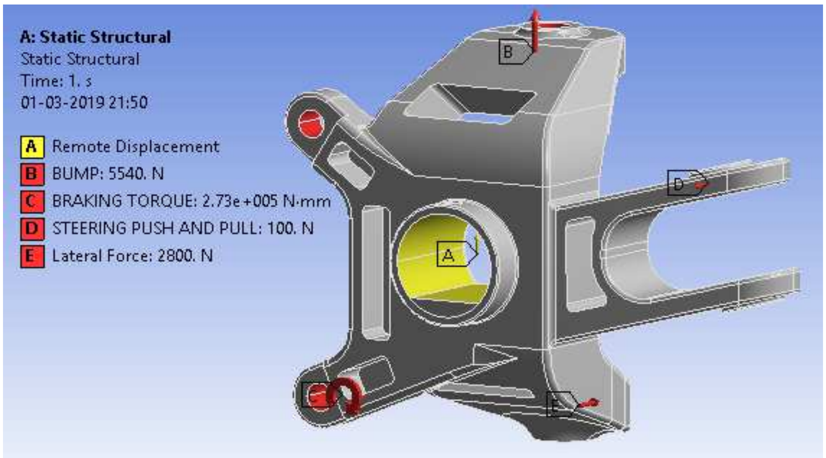

Figure 8: Analysis Model Setup with all the Force acting on the Upright.

Analysis Result

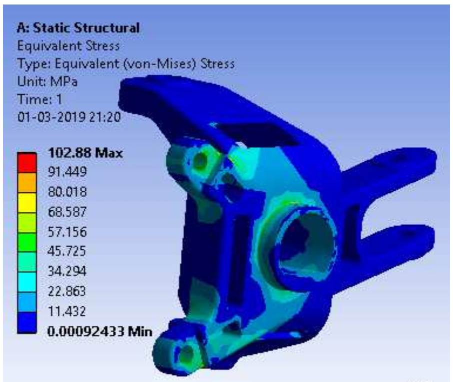

Figure 9: Braking Torque.

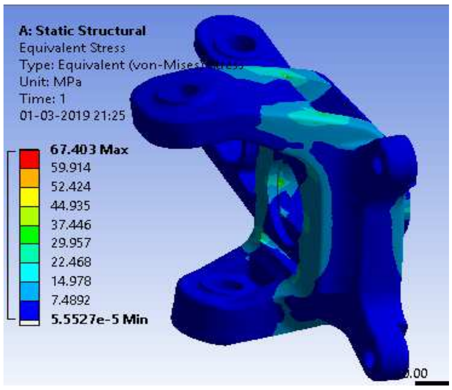

Figure 10: Lateral Force.

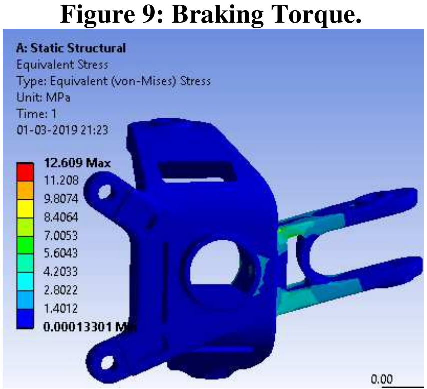

Figure 11: Steering Force.

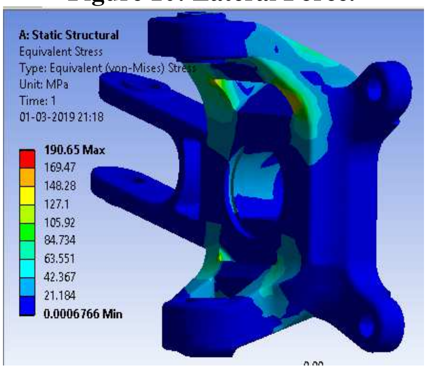

Figure 12: Bump Force.

CONCLUSIONS

The upright with required factor of safety and minimum deformation is been designed and analysed. The amount of stress formation was minimum with reference to the working stress of the material used. The upright design can support both fixed and floating type axel. The upright have required amount of king pin inclination to reduce the scrub radius of the vehicle. In additional, the required caster angle embedded on the upright to contribute more over straight-line stability. The unsprung mass of the vehicle decreased with increase in ride comfort and fuel economy.

Table 6: Final Results Obtained

Results	Minimum	Maximum
Factor of Safety	2.22	15
Deformation (mm)	0.46	0.76
Von Mises Stress (Mpa)	0.675	245.1

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